

Polarimetric Radiometer and Scatterometer Measurements of Hurricane Ocean Winds

William J. Wilson, Simon H. Yueh, Brian Laursen, Steven J. Dinardo, and Rudy Lay

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Mail Stop 168-327
Pasadena, California 91109
Phone: (818) 354-5699
FAX: (818) 393-4683
E-mail: william.j.wilson@jpl.nasa.gov

Abstract - In September 1997, aircraft measurements of hurricane ocean surface winds were made over hurricane ERIKA which was located east of Bermuda. The microwave instruments included three polarimetric radiometers at 17, 19 and 37 GHz and a 14 GHz scatterometer. These instruments were mounted on the NASA P-3 aircraft and were flown around several locations near hurricane ERIKA to measure the azimuthal dependence of the polarimetric wind signal versus incidence angle. Estimates of the wind speed and direction were obtained using dropsondes dropped from the aircraft. Measurements of all 4 Stokes parameters of the ocean signal were made. In area where there were high winds of 35 m/s and scattered clouds, there was a clear azimuthal signal in all the radiometric Stokes parameters, and in the scatterometer signal. Each of these signals was correlated with the wind direction. The radiometric wind signal was similar in all frequencies; however, there was significant variation with the incidence angle. At the larger incidence angles of 55 and 65 degrees, the fourth Stokes parameter, "V" had a peak to peak amplitude of ~ 1 K.

INTRODUCTION

Using polarimetric radiometers to measure ocean wind direction is a technique which has been developing since 1990 [1, 2, 3]. However, all previous measurements were made for wind velocities < 20 m/s, and there was a question as to whether the directional azimuth polarization signature would be present at very high wind speeds where the ocean surface was very turbulent. The purpose of these measurements was to remotely measure the directional properties of the ocean surface, with a radar and polarimetric radiometers, at very high wind speeds, e.g., in a hurricane.

HURRICANE MISSION

In the summer of 1997 a suite of microwave instruments was installed on the NASA P-3 aircraft based at Wallops Virginia. This included instruments from JPL, NRL, NOAA ETL, Georgia Tech, U. Mass. and Wallops. In addition there were dropsondes from NOAA which were used to provide

direct measurements of the wind speed and direction near the ocean surface. Two flights were made over Hurricane ERIKA in the Atlantic Ocean on September 10 and 11 when it was located ~ 700 km east of Bermuda. The first flight obtained data through heavy clouds at a point where the surface winds were measured to be 25-28 m/s. In the second flight, three positions were measured with winds from 22-35 m/sec with broken clouds to complete overcast with precipitation.

The JPL instrumentation consisted of three polarimetric radiometers of 17, 19 and 37 GHz and a 14 GHz polarimetric scatterometer. The 19 and 37 GHz radiometers and the scatterometer have been previously described [3, 4]. The 17 GHz radiometer was a new instrument designed to simultaneously measure all four polarimetric Stokes parameters. All radiometers were mounted looking out the side of the aircraft and circles were made around the measurement points at different roll angles to provide the azimuth data versus incidence angles of 45°, 55°, and 65°. The scatterometer antenna was mounted on the bottom of the aircraft and was either rotated or fixed at specific incidence angles during data measurements.

This paper will discuss the JPL radar and polarimetric radiometers and the results from the high wind observation.

HURRICANE MEASUREMENTS

A complete set of the radar and polarimetric radiometric data for September 11, 1997, with the surface wind at 32 m/s at an incidence angles of 35° to 65°, is shown in Figure 1. (The incidence angle of the scatterometer is 10° less than the radiometer because of limitations on the scatterometer antenna pointing mechanism.)

These plots show two polarizations of the scatterometer backscatter data along with all four of the radiometric Stokes parameters versus the instrument azimuth angles as the aircraft circled. During the circles shown in Figures 1 and 2, the sky was mostly clear with a few broken clouds. The

effects from the clouds can be seen in the unpolarized (I) and difference (Q) radiometric data where the 37 GHz data are above or below the 17 and 19 GHz measurements. However, the effects of the clouds are greatly reduced in the scatterometer and the U and V polarimetric radiometer data.

In the larger incidence angle measurements (55°/65°) shown in Figure 3, it was cloudy, and all the data show the influences of the clouds. However, the 17 GHz U and V data appear to have the least effect.

These data clearly show the direction signal even at the high wind velocity of 32 m/s. The scatterometer data has a strong second harmonic component with 2-3 dB peaks both in the upwind and downwind directions. The VV backscatter is typically 1 dB larger than the HH data. The polarimetric radiometer has both first and second harmonics. Also the Q data has a $\cos(Az)$ dependence, while the U and V data have a $\sin(Az)$ dependence as noted in our previous measurements [2, 3]. However, the amplitude of the harmonics are clearly functions of the incidence angle as shown in Figures 1-3. Also note that the circularly-polarized Stokes parameter, V is mainly a second harmonic function and the amplitude increases with the incidence angle. The amplitude of the U and V directional signals are similar to data with wind velocities ~15 m/s, indicating that the amplitude of these signals are nearly saturated.

CONCLUSIONS

Measurements of the radar backscatter and radiometer polarimetric signals are made over Hurricane ERIKA in September 1997 clearly show a strong azimuth signal correlated with the wind direction. These measurements show that this technique can be used to remotely measure wind direction in areas with very high winds.

ACKNOWLEDGMENTS

This research was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contracts with the National Aeronautics and Space Administration and the National Polar-Orbiting Operational Environmental Satellite System Integrated Program Office.

REFERENCES

[1] M. S. Dzura, V. S. Etkin, A. S. Khrupin, M. N. Pospelov, and M. D. Raev, "Radiometers-polarimeters: Principles of design and applications for sea surface microwave emission polarimetry," in Proc. Int. Geosci. Remote Sensing Symp., Houston, TX, 1992.

[2] S. H. Yueh, W. J. Wilson, F. K. Li, W. B. Ricketts, and S. V. Nghiem, "Polarimetric measurements of sea surface brightness temperatures using an aircraft K-band radiometer," IEEE Trans. Geosci. Remote Sensing, vol. 33, no. 1, pp. 85-92, 1995.

[3] Simon H. Yueh, William J. Wilson, Fuk K. Li, Son V. Nghiem, and William B. Ricketts, "Polarimetric brightness temperatures of sea surfaces measured with aircraft K- and Ka-band radiometers," IEEE Trans. Geosci. Remote Sensing, vol. 35, no. 5, pp 1177-1187 1997.

[4] S. V. Nghiem, F. K. Li, and G. Neumann, "The dependence of ocean backscatter at Ku-band on oceanic and atmospheric parameters," IEEE Trans. Geosci. Remote Sensing, vol. 35, no. 3, pp. 581-600, 1997.

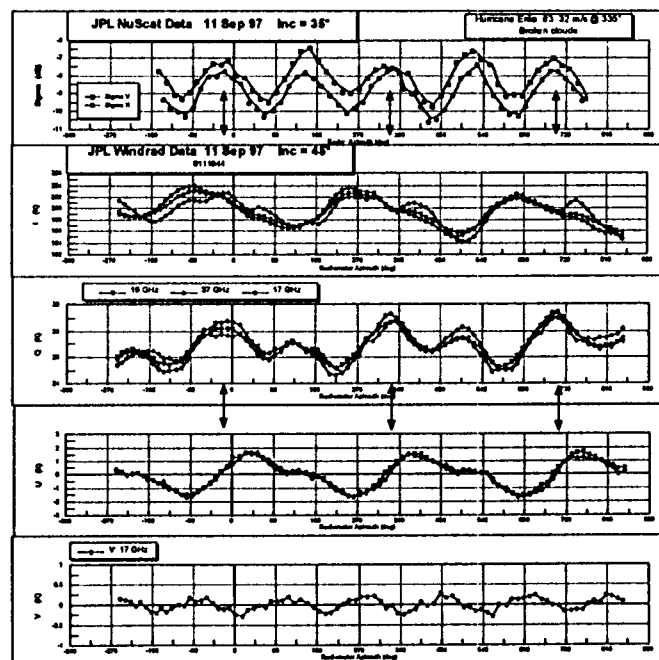


Figure 1. Measured 14 GHz scatterometer data and 17, 19 and 37 GHz polarimetric radiometer data on September 11, 1997 as a function of azimuth angle for an incidence angle of 35° and 45°. The wind speed was 33 m/s, the direction was 348°, and is marked by the arrows. The weather was broken clouds. I is the unpolarized Stokes parameter $\langle T_v + T_h \rangle$, Q is their difference ($T_v - T_h$), U is the difference between T_{45} and T_{135} and V is the circularly polarized difference ($T_{LC} - T_{RC}$). Data are plotted continuously in azimuth angle with increments of 360° added for each additional circle flight.

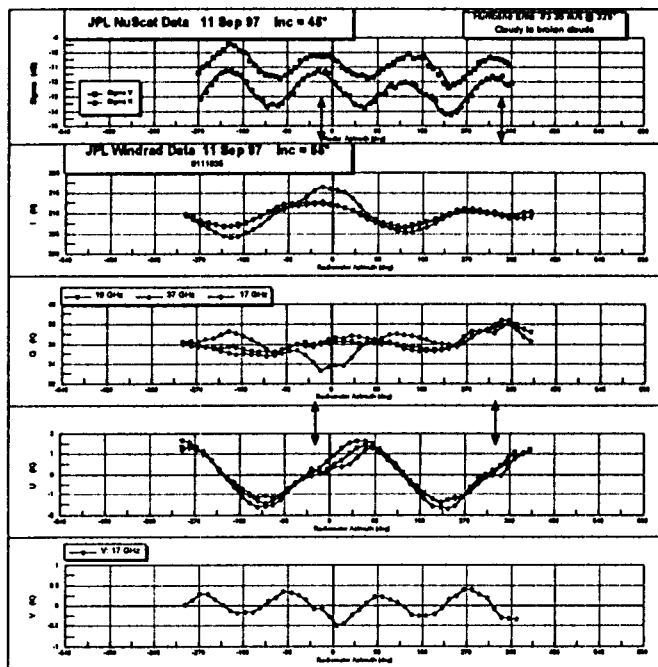


Figure 2. Measured 14 GHz scatterometer data and 17, 19 and 37 GHz polarimetric radiometer data on September 11, 1997 as a function of azimuth angle for an incidence angle of 45° and 55°. The wind speed was 35 m/s, the direction was 325°, as marked by the arrows. The weather was cloudy to broken clouds.

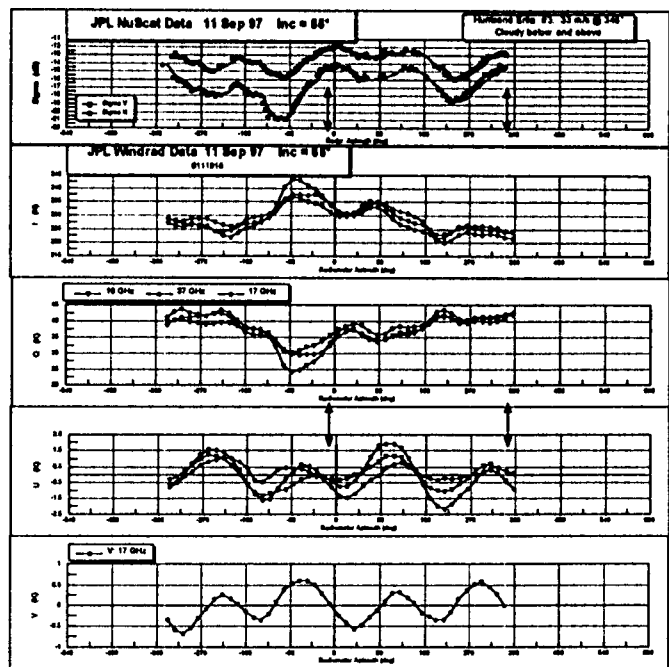


Figure 3. Measured 14 GHz scatterometer data and 17, 19 and 37 GHz polarimetric radiometer data on September 11, 1997 as a function of azimuth angle for an incidence angle of 55° and 65°. The wind speed was 33 m/s, the direction was 348°, as marked by the arrows. The weather was cloudy above and below with some precipitation.